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LONG-TERM REPRODUCIBILITY OF SMALL-SCALE TESTS USED FOR MEASURING THE FLAMMABILITY OF CONVEYOR BELTING

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by

K.J. Mintz* and M.J. Boyle**

ABSTRACT

Oxygen index, flame, and hot-plate ignition tests were carried out on samples of conveyor belting over an extended time period. It was found that the oxygen index test yielded very precise and reproducible results, and therefore would be well-suited for quality control. The flame test, on the other hand, yielded very scattered data. The hot-plate ignition test results were intermediate between the other two tests. No evidence was found to indicate that normal laboratory fluctuations in temperature or relative humidity influence the test.

Key Words: conveyor belts, flammability tests, fire resistance

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REPRODUCTIBILITÉ À LONG TERME D'ESSAIS À L'ÉCHELLE DE LABORATOIRE POUR MESURER L'INFLAMMABILITÉ DES BANDES DE TRANSPORTEURS

par

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RÉSUMÉ

Des essais de longue durée relatifs à l'indice d'oxygène, la flamme et l'allumage de la plaque chauffante ont été menés au moyen d'échantillons de bandes de transporteurs. Les résultats de l'essai portant sur l'indice d'oxygène étaient très précis et reproductibles et, par conséquent, se prêteraient bien au contrôle de la qualité. D'autre part, des données très dispersées ont résulté de l'essai à la flamme. Les résultats du contrôle de l'allumage de la plaque chauffante se situaient à une échelle intermédiaire, entre les résultats des deux autres essais. Aucun fait n'a démontré que les fluctuations normales de la température ou l'humidité relative du laboratoire avaient des conséquences sur l'essai.

Mots clé: bandes de transporteur, essais d'inflammabilité, réfractaire

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INTRODUCTION

The usefulness of a test for measuring the fire-resistance of a product depends primarily on three factors: validity, ease of application and reproducibility. For conveyor belting used in underground mines, the most valid test is obviously a full-scale trial in a real mine. However, the reproducibility of that type of test is hard to establish and it is certainly not easy to carry out. A medium-scale test, the propane gallery, is widely considered to be of sufficient size that it does provide a reasonable measure of relative flammability. Even for that test, it is difficult to establish its reproducibility and it is expensive to carry out. Small-scale tests are certainly easy to carry out, but controversy exists on their relevance. Furthermore, there has been insufficient work to establish their reproducibility. The present paper deals with the latter issue, which is crucial for a quality control program.

Three small-scale tests were used in this study. The critical oxygen index (COI) test is a well-established standard for plastics (1). Small-scale flame tests have been used extensively for certifying conveyor belting. The one used here is a modification of that used by the U.S. Mine Safety and Health Administration (2). It has been described and compared with the Barthel Burner test in a previous paper (3). The third test, the hot plate ignition (HPI) test, is one developed recently in this laboratory (4).

The purpose of this study was to determine how the results of these three small-scale tests vary with time and ambient conditions.

EXPERIMENTAL

Two types of belting, both with fabric carcasses, were chosen for this study: sample "A" had PVC covers; type "B" had rubber covers. Samples were cut from a single piece of belting, numbered, then fully randomized using random numbers. Operators #1 and #2 refer to the authors.

Tests were carried out over 11 months in a laboratory that was not air-conditioned. Hence, the humidity varied drastically, with some variation also in the temperature.

The flame test has been described elsewhere (3). Tests were carried out only in still air; flameout times only were measured. (The beltings were chosen to have minimal afterglow, which can be much more variable.) Ten trials were carried out in each set.

The COI test was carried out according to the ASTM Standard (3). The only deviation was that the data was analyzed by the Bruceton up-and-down method, as modified by Dixon for small sample sizes (4). Six samples were tested in each set. Careful attention was taken to ensure that each sample was properly ignited, a necessary condition to obtain reproducible results.

The HPI test measures the propensity of a 25 mm square sample to ignite on a hot surface. The "10-s ignition temperature" is taken as that temperature at which the sample takes 10 s to ignite. The minimum ignition temperature is the lowest temperature of the surface at which the sample will ignite, no matter how long it is left there. Details of the apparatus and method have been given elsewhere (5).

RESULTS AND DISCUSSION

CRITICAL OXYGEN INDEX TEST

The results (see Table 1) indicate that the COI is independent of ambient humidity and temperature (in the range studied), and that it does not change over a lengthy period of time. Although the mean values for the two operators are very close, the Student t-test shows that the means are statistically different at the 99% significance level. This implies that the two operators use slightly different techniques, which affect the results. The reason that the difference between operators can be isolated is that the random scatter of data is so small. Although the difference is not of practical importance, it leads to the suspicion that tests done in different laboratories may be significantly different unless an effort has been made to use exactly the same techniques. In the authors' opinion, the technique of ignition of the sample is the critical factor. The ignitor flame must be held onto the top of the sample sufficiently long to ignite the whole top surface of the sample simultaneously, but the flame must be kept away from the rest of the sample.

MODIFIED MSHA FLAME TEST

The mean and standard deviation of each set of 10 samples are given in Table 2. The first step of the statistical analysis is to decide on whichdistribution fits the data. The W-test, developed Shapiro and Wilks (6), is able to test the fit of small sets of data to the normal and log-normal distributions. Of the 23 sets, 5 were not normal (at the 95% significance level) but only 3 were not log-normal. On 16 of the 23 sets, the log-normal gave a better fit than the normal. Hence, it seems reasonable to use the log-normal distribution for the remainder of the analysis.

In order to determine whether the means listed in Table 2 are different, analyses of variance (ANOVA) were carried out on the means of the logs of the flameout times. (The standard deviations of the latter, although scattered, satisfy Bartlett's criterion for homogeneity of variances and thus allow the use of the ANOVA. On the other hand, the standard deviation of the flameout times do not satisfy Bartlett's criterion.) For product #1, considering only operator #1, the means of the individual sets are different at the 99.9% significance level. Hence, the sets cannot be combined. Similarly, the means for operator #2 are different at the 99% level and the means for product #2 are different at the 97.5% level.

The reason for the variation amongst the means of the sets is unknown. There is only a slight variation with relative humidity, essentially no correlation with temperature and no significant variation with time (which could have resulted from aging of the belting or equipment deterioration). Possibly the flameout times are very sensitive to very minor changes in the positioning of the sample with the flame. The fact that product #2 has less scatter than product #1 may indicate that different products have different degrees of sensitivity to this factor.

The normal distribution provides a better fit of the data to the means than the log-normal distribution, according to the Shapiro-Wilks criterion. This implies that the effects causing the differences between sets is different from the effects causing the scatter within each set.

Because of the scatter of results in the flame test, the regulator is concerned about the possibility of false passes. (The manufacturer is, of course, concerned about the possibility of a false failure.) Assume that the ratio of the standard deviation to the mean of product #1 is typical (0.4) for

the means of sets of 10. Consider a hypothetical product of true mean flameout time of 20 s [this is the boundary between passing and failing the flame test in the Canadian Standard for fire-retardant conveyor belting (7)]. If itbe desired to have a 95% probability of not accepting a false pass and, assuming normal distribution, then any mean flameout time above 8 s would be unacceptable. (If smaller sample sizes were used, as is actually the case, then the upper limit of acceptability would be even lower.)

A similar argument can be made regarding quality control tests. For the above example, if the repeat test were anywhere from 8 to 32 s, then the product could not be considered to have changed (at the usual 5% significance level). The acceptable range would be even larger if one did not have a good estimate of the "true" mean, but had carried out only one set of tests.

HOT-PLATE IGNITION TEST

A typical set is shown in Fig. 1. The "time to ignition" is the time between placing the sample on the hot plate and the time that it bursts into flames. The arrow points indicates that the sample did not burst into flames within 120 s at that temperature. (Usually by that time the sample has completely charred, so that ignition is no longer possible.) A curve is drawn through the points and the "ten-second ignition temperature" is read off the abscissa. The minimum ignition temperature can be estimated from the graph, with somewhat less accuracy.

The ignition temperatures are shown in Table 3. Welch's test (8) shows that the operators obtained statistically different minimum ignition temperatures, but not different 10s ignition temperatures. Furthermore, the latter had significantly smaller standard deviations than the former.

There is no evidence for any significant change with time over the 9 month period in which these tests were carried out, nor any variation with ambient humidity or temperature.

CONCLUSIONS

For quality control purposes, the COI test is clearly the best of the three, since it provides a very reproducible, precise value. It is widely used for that purpose for plastic materials. The COI has been shown to re-

late directly to the quantity of fire-retardants present in a plastic material (9). Although objections have been raised to its use for composite materials such as conveyor belting, based partly on the lack of reproducibility amongst laboratories, the authors believe that these problems can be overcome by careful attention to standardizing details of the testing procedures.

Our work also indicates that the HPI test can also be used for quality control purposes. It is, however, less precise and reproducible than the COI test. On the other hand, the flame test is unsuitable as a quality control test, except to detect extremely gross errors. From the author's previous work (3), alternative flame tests such as the Barthel Burner test would not provide any better results.

The one advantage of the flame test is that it appears to represent a more realistic situation than the COI test, and therefore can be useful as a demonstration to non-experts. As shown above, however, flame test data must be treated with caution to prevent either false passes or false failures.

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Table 1 - Critical oxygen index test results

	Operator #1			Operator #2		
Set No.	Temp (°C)	R.H.	COI (% O_2)	Temp (°C)	R.H.	COI (% O_2)
1	22	37	26.4	24	53	26.4
2	24	56	26.6	22	49	26.3
3	24	42	26.2	26	60	26.3
4	27	32	26.4	22	53	26.3
5	19	45	26.6	24	58	25.9
6	21	62	26.8	22	10	26.0
7	23	29	26.4			
8	21	15	26.6			
Mean			26.5			26.2
Standard Deviation			0.2			0.2

Table 2 - Mean and standard deviation of flameout times of small-scale flame tests

Set No.	Operator #1 Temp (°C)	R.H. (%)	Product #1	Product #2	Operator #2 Temp (°C)	R.H. (%)	Product #1
1	24	37	11.6 ± 9.0	25.3 ± 8.3	24	18	16 ± 11
2	25	49	18.5 ± 13.0	23.6 ± 13.1	22	52	18 ± 7
3	22	41	11.3 ± 10.3	26.2 ± 8.4	26	61	16 ± 13
4	27	30	4.5 ± 3.7	21.8 ± 4.7	22	51	13 ± 7
5	21	41	9.5 ± 5.2	29.8 ± 6.4	23	66	23 ± 16
6	23	59	18.5 ± 8.7	23.3 ± 8.7	19	12	5.6 ± 2.6
7	23	30	23.7 ± 11.4	34.2 ± 7.2	19	15	10.0 ± 5.3
8	22	21	10.0 ± 5.4	26.1 ± 6.8			

Note: Product #1 is a conveyor belting with PVC covers; Product #2 is a conveyor belting with rubber covers.

Table 3 - Hot-plate ignition test results (product #1)

Set No.	10-s ignition temperature (°C)		Minimum ignition temperature (°C)	
	Operator #1	Operator #2	Operator #1	Operator #2
1	695	680	680	650
2	690	670	680	660
3	690	690	680	660
4	690	675	670	660
5	690	680	670	640
6	690	695	680	680
7	685	-	670	-
Mean	690	682	676	658
Std. Dev	3	9	5	13

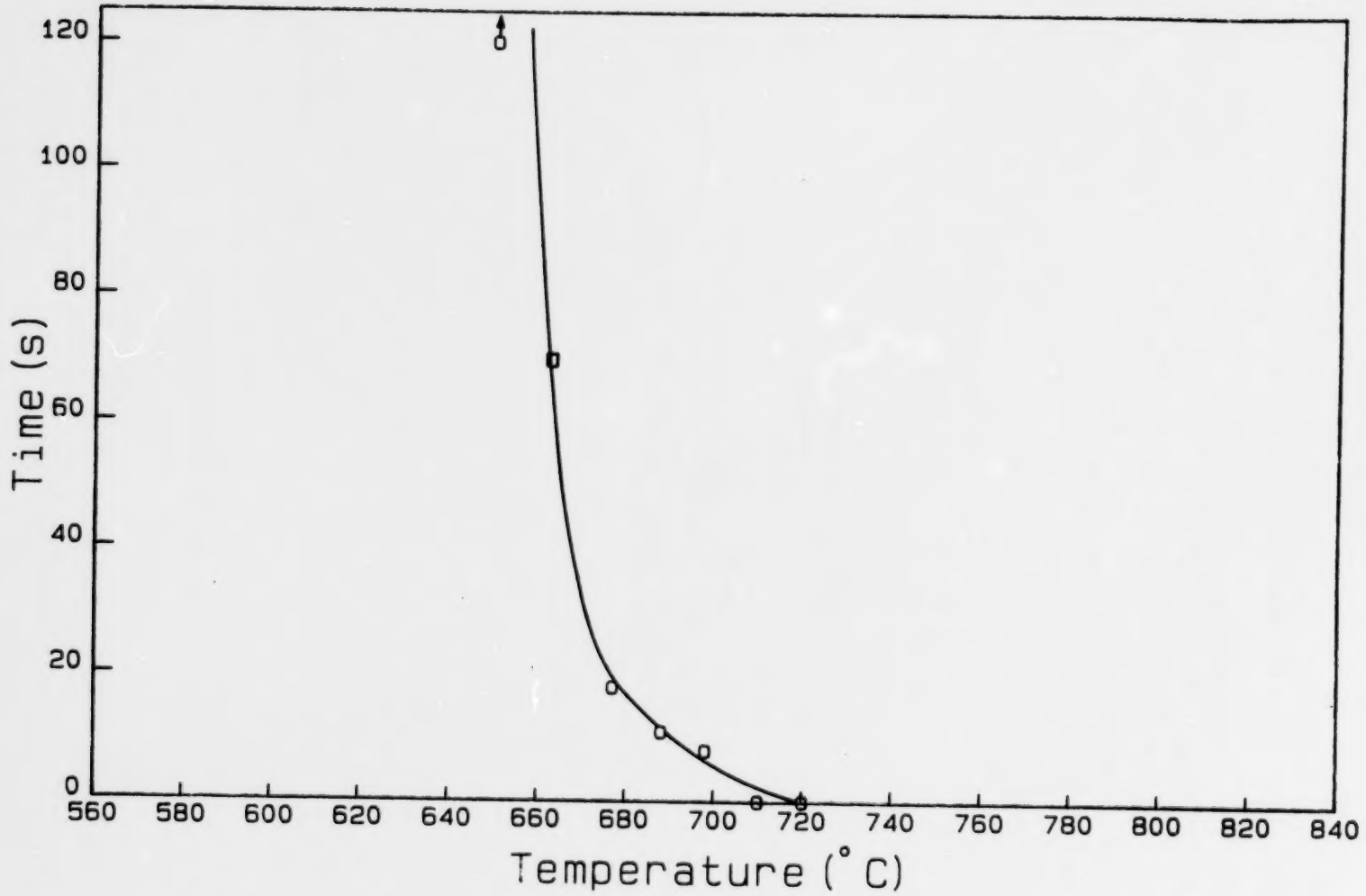

Fig. 1 - Hot-plate ignition test.

APPENDIX
STATISTICAL ANALYSIS OF THE DATA

CRITICAL OXYGEN INDEX TESTS

An example of the method used to determine the COI (A1) is shown in Table A1. The COI apparatus currently used in this laboratory is incapable of any better precision than about ±0.2 - 0.5% O_2, depending on the visual acuity of the operator. The data suggest that closer spacing of test levels would be desirable, but that would require a more accurate instrument.

FLAME TESTS

The actual flameout data are presented in Table A2, which were used to calculate the means and standard deviations given in Table 2. The most powerful test for determining if a small set of data can be reasonably considered to be normal or log-normal is the W-test developed by Shapiro and Wilks (A2). The smaller the value of W, the more likely that the given set was not drawn from a normal distribution. For a sample size of 10, if W is less than 0.842, there is less than one chance in 20 that the sample could have come from a normal distribution. The W values for each set are shown in Table A3. Although the values cannot be proven to follow a given distribution, the log-normal empirically provides a closer representation of the data than the normal, and in fact appears to be adequate for the remainder of the statistical analysis.

The Bartlett statistic M provides a test of the hypothesis that the several variances have a common value (A3). This is the basic assumption of the ANOVA technique. For the normal and log-normal distributions, the M values (using Hartley's modification) are as follows:

	M - from data		M - from table
	Log-normal	Normal	(5% level)
Operator #1, product #1	8.18	19.74	14.07
Operator #2, product #1	2.84	29.45	12.95
Operator #1, product #2	10.10	10.82	14.07

Since the M values from the data are smaller than the table values for the log-normal distribution, then there is no difference amongst the variances at the 5% level of significance. On the other hand, for the normal distribution for product #1 (both operators), the variances are inhomogeneous and hence application of the ANOVA would not be valid.

The ANOVA statistical tests using the log-normal distribution are shown in Table A4. (The ANOVA tests based on the normal distribution also show that there are real differences amongst the means of the sets.)

In order to test whether or not the operators obtained statistically different results, the Welch test (A4) can be applied to the overall means of each operator. The relevant statistic, is defined by:

$$v = \frac{\mu_2 - \mu_1}{[(\sigma_1/n_1)^2 + (\sigma_2/n_2)^2]^{1/2}}$$

where:
μ is the mean,
σ is the standard deviation for the distribution of the means,
and the subscripts refer to operators 1 and 2, respectively.

Its value is 0.298 which is much less than the table value of V(0.52; 7, 6, 0.025) = 2.08 (95% confidence level). Hence, there is no statistically significant difference between operator #1 and operator #2. This finding may be caused by the very large scatter in the data.

The effect of humidity on flameout time is shown in Fig. A1. The circles are product #1, and the crosses are product #2. The lines are the least-squares fit and have coefficients of correlation 0.57 and -0.32, respectively. Although one would expect the flameout time to be shorter if the humidity were higher, the evidence does not support that hypothesis.

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Table A1 - Typical oxygen index test data

	Trial					
% O_2	1	2	3	4	5	6
27.0		X				X
26.5	O		X		O	
26.0				O		

Note: X = samples burning for more than 3 min.

O = samples burning for less than 3 min.

COI = 27 + 0.5(-0.831) = 26.6

Table A2 - Flameout times in the small-scale flame test

Product No.	Operator No.	Set No.	Time (s)
1	1	1	9.3, 4.1, 4.5, 3.0, 9.1, 26.5, 23.0, 5.8, 7.7, 23.1
1	1	2	21.0, 18.2, 24.1, 25.1, 4.6, 44.6, 3.8, 27.0, 2.5, 13.9
1	1	3	5.5, 14.4, 35.6, 3.6, 2.7, 13.7, 2.0, 12.7, 17.7, 4.7
1	1	4	3.0, 2.1, 4.8, 2.2, 4.0, 2.0, 13.3, 3.4, 1.9, 8.7
1	1	5	5.0, 6.5, 11.1, 9.1, 21.8, 3.1, 11.1, 6.4, 8.7, 11.8
1	1	6	20.1, 7.6, 23.3, 26.1, 7.9, 7.4, 20.2, 29.9, 28.3, 14.2
1	1	7	20.6, 12.8, 9.5, 16.2, 38.0, 29.0, 19.2, 17.6, 28.3, 45.6
1	1	8	5.0, 8.2, 19.2, 2.9, 4.5, 14.2, 7.2, 16.4, 11.8, 10.6
1	2	1	19, 12, 35, 8, 11, 7, 20, 4, 8, 35
1	2	2	3, 19, 24, 16, 31, 14, 21, 15, 19, 14
1	2	3	12, 27, 42, 9, 6, 3, 25, 21, 6, 6
1	2	4	9, 7, 9, 11, 22, 14, 20, 23, 4, 8
1	2	5	21, 12, 12, 18, 59, 32, 7, 37, 18, 14
1	2	6	3.6, 6.7, 8.7, 6.0, 3.6, 5.6, 3.1, 9.4, 1.4, 7.4
1	2	7	6.4, 18.6, 11.9, 7.7, 5.0, 16.9, 6.0, 4.3, 7.7, 15.8
2	1	1	18.5, 19.2, 29.1, 23.3, 27.7, 33.3, 9.0, 25.7, 28.8, 38.6
2	1	2	16.3, 17.8, 37.7, 54.3, 18.7, 14.7, 18.0, 17.5, 12.8, 27.8
2	1	3	19.7, 23.7, 30.9, 23.6, 17.9, 18.4, 30.6, 44.2, 33.1, 20.2
2	1	4	23.1, 13.8, 16.1, 16.0, 24.8, 23.1, 25.9, 24.3, 26.8, 24.5
2	1	5	27.6, 38.4, 26.6, 29.6, 28.1, 17.1, 30.6, 28.2, 31.8, 40.3
2	1	6	19.1, 19.1, 33.1, 13.2, 42.5, 17.3, 21.8, 21.1, 26.8, 19.0
2	1	7	27.3, 25.2, 31.2, 43.8, 33.6, 35.7, 32.5, 48.2, 36.6, 28.4
2	1	8	28.1, 18.5, 34.3, 21.3, 38.1, 22.9, 25.9, 17.5, 23.0, 31.0

Table A3 - Test of validity of normal and log-normal distributions of flameout times in the modified MSHA test

Product No.	Set No.	W-value (Operator #1)		W-value (Operator #2)	
		Normal	Log-normal	Normal	Log-normal
1	1	0.807	0.914	0.840	0.948
1	2	0.927	0.878	0.951	0.754
1	3	0.824	0.950	0.869	0.945
1	4	0.744	0.882	0.894	0.943
1	5	0.874	0.973	0.846	0.974
1	6	0.893	0.841	0.965	0.910
1	7	0.932	0.981	0.866	0.916
1	8	0.59	0.962		
2	1	0.976	0.872		
2	2	0.754	0.858		
2	3	0.879	0.920		
2	4	0.828	0.802		
2	5	0.919	0.878		
2	6	0.859	0.937		
2	7	0.935	0.967		
2	8	0.952	0.969		

Mean W: normal distribution - 0.882

log-normal distribution - 0.912

Table A4 - ANOVA for log of flameout times

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio	$F_{.05}$	$F_{.001}$
		Product #1, Operator #1				
Between sets	3.8699	7	0.5528	5.78	2.15	4.0
Residual variability	6.9193	72	0.0961			
Total	10.7892	79				
		Product #1, Operator #2				
Between sets	2.1878	6	0.3646	4.78	2.23	4.3
Residual variability	5.0196	63	0.0797			
Total	7.2074	69				
		Product #2, Operator #1				
Between sets	0.3430	7	0.0490	2.61	2.15	4.0
Residual variability	1.3502	72	0.0188			
Total	1.6932	79				

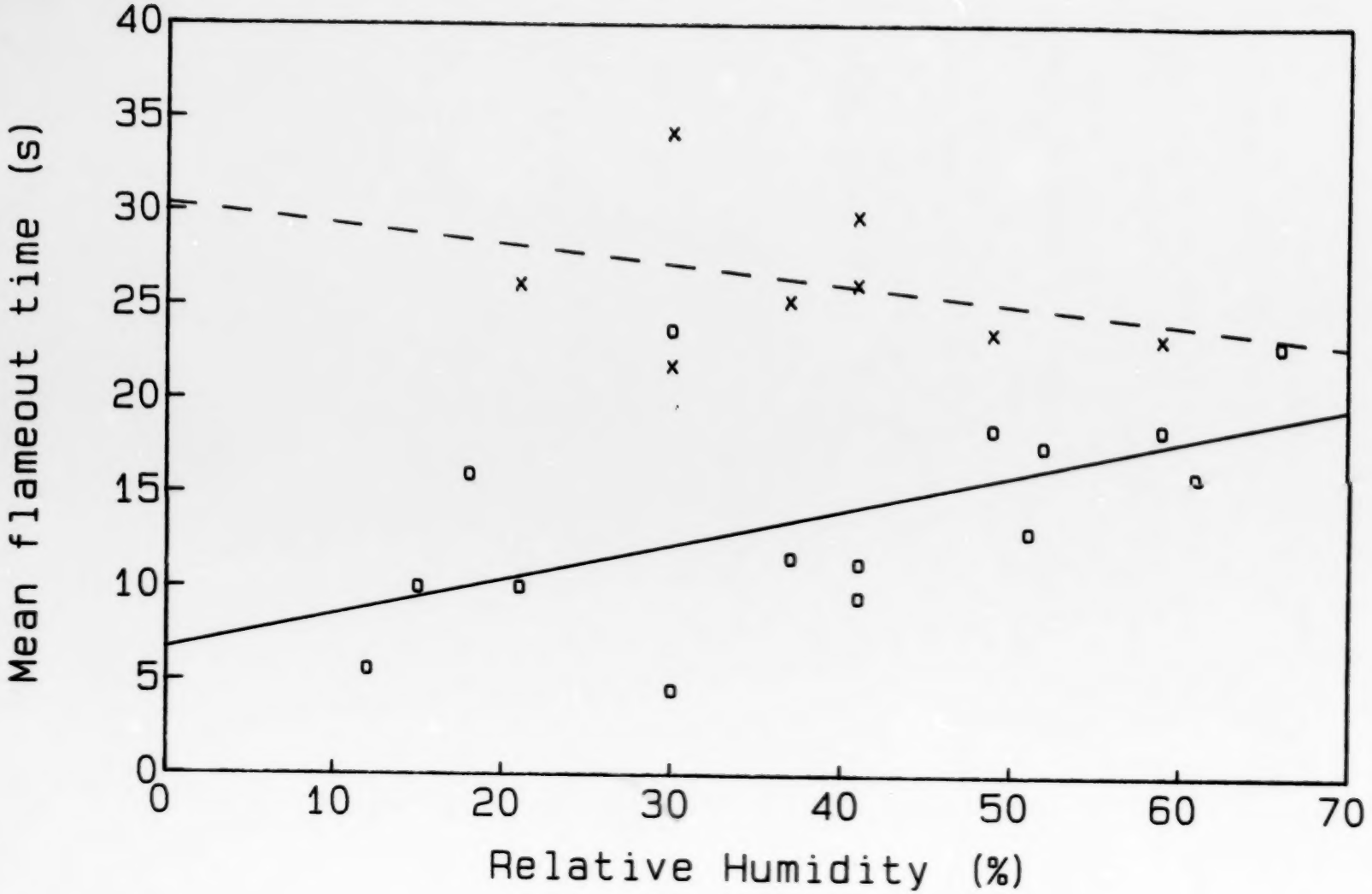

Fig. A1 - Effect of relative humidity on the flameout time